RESEARCH DEPARTMENT

COLOUR TELEVISION:

THE ADAPTATION OF THE N.T.S.C. SYSTEM TO U.K. STANDARDS

PART 3: A TRIPLE VIDEO CHANNEL FOR USE WITH A COLOUR SLIDE OR FILM SCANNER

Report No. T-060/3

(1957/5)

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SUMMARY

A triple video channel has been developed for use with colour slide or film scanning apparatus. This channel includes all the signal correction and modifications necessary to provide standard colour separation signals suitable for coding. An outline is given of the considerations influencing the design; the remainder of the report is devoted to a description of the apparatus.

1. INTRODUCTION

Previous reports[1, 2] have described respectively the basic elements and the practical development of colour film and slide scanning apparatus. Such equipment performs the operations of image analysis and colour separation, and provides output signals representing the red, green and blue separation components of the film or slide.

In general, each of the three channels associated with the scanning equipment will be similar in that the operations performed will be identical, and therefore the remainder of this discussion will refer to one channel only.

2. GENERAL

The modification of each photocell output to form a television signal of standard electrical characteristics involves several processes. These include:

(a) correction for the scanning tube afterglow,

(b) correction for the effective scanning aperture, and

(c) modification of the contrast law to that required by the display device.

2.1. Afterglow Correction

The scanning raster is produced at the fluorescent screen of the scanning cathode-ray tube by exciting each point of the screen in turn. The light output from

each scanned point, however, persists for some time after excitation has ceased and therefore each point of the picture is represented by an electrical signal which persists in a similar manner. If this screen persistence or afterglow has a short duration and obeys a simple law, correction can be effected by relatively simple means.

The choice of a suitable phosphor for use in a colour television flying-spot scanner is usually governed by the requirement of a short and easily corrected afterglow, together with a suitable emission spectrum. Hence the great majority of present day colour scanning equipments employ the P15 phosphor (Hex. ZnO : [Zn]) whose afterglow characteristic conforms to an exponential fall over a considerable proportion of the decay and whose emission spectrum is continuous over the range 420 to 650 mμ.

The general form of the afterglow correction characteristic may be deduced from a consideration of that which would be required if the afterglow characteristic conformed exactly to the exponential form. In such a case the brightness, b, of a point on the screen of the scanning tube may be represented by

$$b = B_o e^{-\alpha t}$$

where B_o is the maximum brightness.

The corresponding photocell output current will be

$$i = I_o e^{-\alpha t}$$

The spectrum of this time function may be written as

$$g(p) = \int_o^\infty e^{-\alpha t} \cdot e^{-pt} dt$$

$$= \frac{1}{\alpha + p}$$

where $p \equiv j\omega$

This characteristic will be corrected if the transfer impedance of the corrector is of the form

$$z(p) \propto \alpha + p$$

This transfer impedance may be obtained with a simple circuit such as the series combination of resistance and inductance.

In practice, however, it is found that the afterglow characteristic of the P15 phosphor operated under normal conditions does not conform sufficiently to a simple exponential decay curve for such a corrector to perform satisfactorily.

The problem of correcting an afterglow characteristic known only in an approximate form may be solved in several ways. One method is illustrated in Fig. 1. The screen of the tube T, displaying a television raster of uniform brightness, is

masked by an opaque screen S placed in contact with the tube: the screen contains a narrow slit lying on the vertical or field axis of the raster. During every line scan, therefore, the slit will be traversed by the scanning spot and a short pulse of light will pass to the photomultiplier P. The output signal from P, after amplification in A, is passed to a variable equaliser E whose parameters are adjusted until the waveform displayed by the oscilloscope O consists of narrow rectangular pulses. The characteristic of the equaliser E is that required for correction of phosphor afterglow in the tube T.

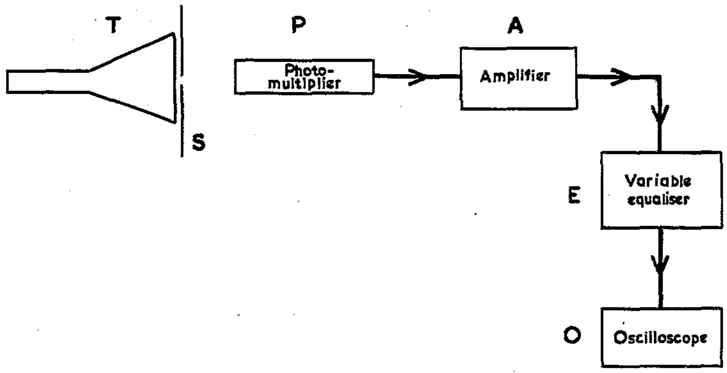

Fig. 1 - Apparatus for measuring afterglow characteristics

If the afterglow characteristic is known to be of a form which may be closely approximated by the sum of several exponential delay characteristics, a form of corrector as illustrated in Fig. 2 may be used.

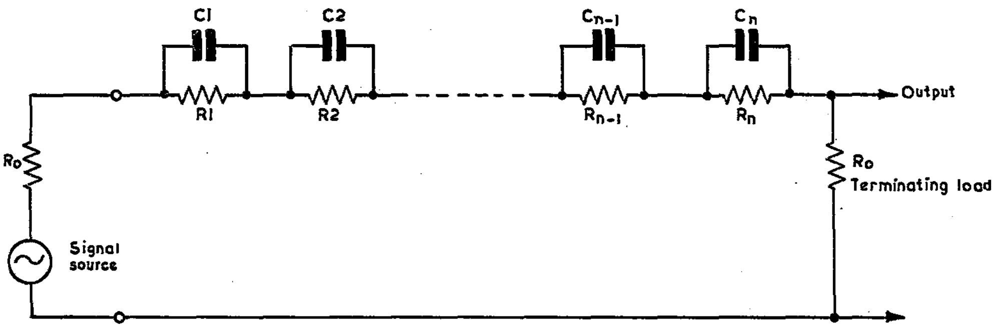

Fig. 2 - General form of afterglow corrector

The zinc oxide (P15) phosphor mentioned previously has an afterglow which may be corrected effectively by means of four time-constants. As a point of interest, its afterglow characteristic has been calculated (see Appendix) from a knowledge of the corrector parameters.

2.2. Aperture Correction

The ability of the apparatus to generate an electric signal which corresponds exactly to the variations in the light transmission of the film or slide encountered by the scanning spot depends primarily upon the size and shape of the spot at the image plane in the film or slide. In order that this process be carried out with the minimum of aperture loss, the spot should have an effective diameter which is small compared with the "picture element" dimension of the television system in use. In practical scanning apparatus this condition is usually not fully satisfied, due to imperfections in such component parts as the cathode-ray tube and the optical system.

The loss of fine picture detail due to each of such items can be expressed in terms of an "equivalent aperture"[3] having certain dimensions and flux distribution, and, where several of such apertures are acting in cascade, the overall effect may be expressed in terms of one "resultant aperture".

The equivalent apertures representing the performance of lenses and cathode-ray tubes are, in general, of symmetrical shape, and usually conform closely to either a Gaussian or a cosine-squared law. If this is the case, equalisation of aperture loss can be achieved by relatively simple means.

The spectrum of the time function due to scanning an infinitely thin slit by such an even aperture function will be of the form

$$f(p) = \frac{1}{\alpha_0 - \alpha_2 p^2 + \alpha_4 p^4 \ldots}$$

and an approximate correction is obtained, therefore, by subtracting, from the output signal, the appropriate amplitude of its second derivative with respect to time[4]. By inspection it will be seen that, by the use of higher even order derivatives of suitable sign, successively more accurate correction may be achieved.

2.2.1. Amplifier Characteristics

Before proceeding to consider further fundamental problems in the design of the video channel, it is of interest to discuss the amplifying chain following the photo-multiplier in the scanner.

There are two main factors to mention; first, the presence of any amplitude non-linearity in amplifiers before the afterglow corrector renders the corrector ineffective. For this reason, the scanner design should either avoid the use of such an amplifier or include an amplifier operating with signals very small compared with the overload level. Secondly, attention must be paid to the transient response of all those circuits, including the afterglow and aperture correction networks, which precede the contrast-law or gamma corrector, in order to avoid objectionable ringing in the output signal. For reasons to be described in the next section, one effect of the gamma correction is to amplify input signals representing low film or slide light transmission more than those pertaining to high transmission. Thus, any transient effects occurring at or near black level will be emphasised by the gamma corrector.

In order to minimise such effects, two approaches to the design of the amplifier are possible. On the one hand, it may be made to have a transient response showing no overshoot or ring, in which case the cut-off frequency will need to be considerably higher than that required to reproduce the finest detail, and the pass-band will therefore include noise components outside the normal video band. In these circumstances, if the signal-to-noise ratio at the input of the gamma corrector is sufficiently low, intermodulation between signal and noise on the non-linear amplitude characteristic may result. On the other hand, if the amplifiers preceding the gamma corrector have a transfer characteristic cutting off sharply at the maximum frequency required, considerable care must be exercised to preserve a constant group delay within this pass-band in order to obtain a satisfactory transient response.

The correction of group-delay distortion may be carried out with sufficient accuracy by the judicious use of constant-resistance all-pass networks inserted at suitable points in the amplifying chain.

2.3. Gamma Correction

The signal available from the aperture corrector may be assumed to represent the scanned transparency of the film for the colours activating one of the three scanner photocells.

As is well known, such a signal is not suitable for the direct control of beam current in a cathode-ray tube, because of the non-linear relationship existing between signal voltage and spot brightness in the cathode-ray tube itself. This cathode-ray tube characteristic is usually expressed as a power law of index "γ", which, in general, has a value lying between 2 and 3. In order that the overall transfer characteristic shall be linear, it is therefore necessary for the electrical signal to be passed through a non-linear amplifier whose characteristic is expressed by a power law of reciprocal index $1/\gamma$.

Due to somewhat wide variations in the contrast characteristics of present-day colour displays, it has, as yet, not proved practicable to define precisely a standard gamma-correction characteristic for use in picture-originating equipment. Colour television standards, both in the U.S.A. and the U.K., assume a display tube power law index of 2·2 and it would appear desirable, therefore, that the gamma corrector be characterised by an index of 0·45. Such an arrangement assumes that the contrast characteristics of both the colour slide or film and the colour picture display device contribute negligible distortion to the reproduced picture. The gamma corrector design described in this report is based on such an assumption, but it may well be found that a worth-while advantage to the viewer may be obtained by deviating somewhat from the overall linear characteristic. Such considerations have been treated in considerable detail elsewhere[5], where it is suggested that a combination of gamma over-correction, together with additional matrix transformations, can lead to the improved reproduction of colour film.

The gamma corrector consists, basically, of a non-linear amplifier for which the input signal and output signal are related by the required power law. Such amplifiers are known[6] and a suitable design may be chosen in terms of the performance required. For the requirements where high stability and close adherence to a fixed power law are of prime importance, the circuit proposed by Nuttall[7] has much to recommend it. In this circuit, a non-linear element in the form of a pentode is placed in the feedback path of a negative-feedback amplifier. A suitable pentode, given certain operating potentials, possesses an anode current/grid voltage characteristic which follows closely a power law whose index lies in the range 2·2 to 2·5. If a signal is applied to the grid in a positive sense from the point of anode current cut-off, the anode current will conform to the applied signal transformed by this power law (as in the display cathode-ray tube). Considering Fig. 3, which shows schematically the

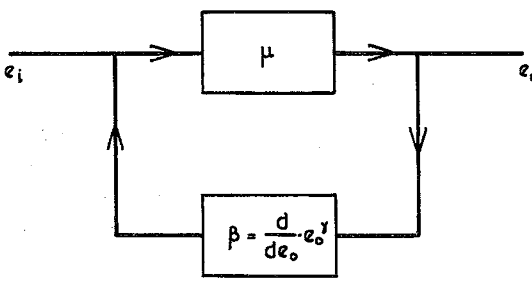

Fig. 3 - Non-linear feedback amplifier

feedback amplifier under discussion, let the forward path have a gain μ and the feedback path β include the above-mentioned non-linear element.

The gain of the circuit will be the ratio of output to input voltages

$$\frac{e_o}{e_i} = \frac{\mu}{1+\mu\beta}$$

For $\mu\beta >> 1$

$$\frac{e_o}{e_i} = \frac{1}{\beta}$$

The transfer characteristic of the feedback path is

$$\beta = \frac{d}{d \cdot e_o} e_o^{\gamma} = \gamma e_o^{\gamma - 1}$$

where γ is the index of the power law expressing the non-linearity.

Hence

$$\frac{e_o}{e_i} = \frac{1}{\gamma e_o^{\gamma - 1}}$$

and

$$e_o = \left(\frac{1}{\gamma} \cdot e_i\right)^{\frac{1}{\gamma}}$$

Hence the overall characteristic is represented by a power law having the reciprocal index $1/\gamma$.

2.3.1. Black Level Stabilisation

It will be appreciated that a gamma corrector whose static transfer characteristic and stability are good can operate only if the signal at the input is free from all distortion. For example, it is essential that the signal at the input should contain the d.c. component in order to ensure that each part of the signal is applied to the appropriate part of the gamma curve. The restoration of d.c. at the corrector input may be carried out by any well-known method, such as a keyed clamp. Such a restoration method would always leave a residual black level error signal, in the form of a line-sawtooth waveform, which would be emphasised by the corrector characteristic due to the high gain at or near black level. This latter effect can be somewhat reduced, as pointed out by Nuttall[7], by transferring the d.c. restoration circuit to the grid of the non-linear valve. However, by the use of a pulsed feedback system incorporating integrators in the feedback circuit, a black level stabiliser may be used which is characterised by error prediction. This form of circuit will operate with no error under steady state conditions and very small errors for large sudden changes of d.c. component.

Such a black level stabiliser has been used with a high-quality black-and-white film scanner and suitable circuits have been discussed in some detail[6, 8].

2.4. Other Operations upon the Signal

After gamma correction, other operations to be carried out on the signal are those of inserting the suppression or blanking pulses and, where necessary, the addition of synchronising signals. Circuits for effecting such operations are very well known. A typical arrangement capable of excellent results employs electronic switches consisting of diodes[9].

3. DESCRIPTION OF THE TRIPLE VIDEO CHANNEL

Fig. 4 shows a photograph of the complete triple channel. This single bay provides the necessary processing for each of the three primary-colour video signals obtained from the photo-multipliers in a scanner and provides outputs suitable for those circuits required to form a composite colour signal. The same bay also contains a pulse distribution unit which forms the pulses required by both the scanner unit and the three video control units; this pulse distribution unit is driven from the system master pulse generator.

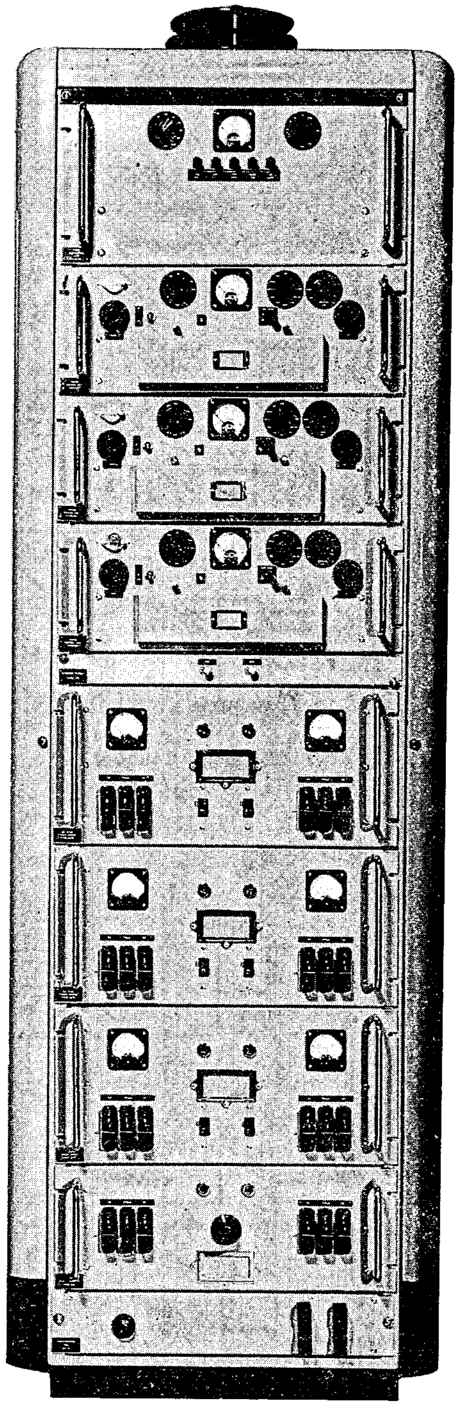

Fig. 4 - Triple video channel

A schematic diagram of one of the three video control units is shown in Fig. 5. The design is based upon those considerations discussed in Section 2.

3.1. The Afterglow Corrector

This consists of the low frequency attenuating network (C1R1, C2R2, C3R3, C4R4), shown in Fig. 10(a), in the form of four adjustable resistors in series with the input circuit, each successive resistor having a progressively smaller capacitance connected in parallel. The decreasing time constant of each CR combination compensates for the shorter components of the streaking which is the visible result of uncorrected afterglow. The input cable and the corrector are terminated by a potential divider, (R5), so providing an input signal level control.

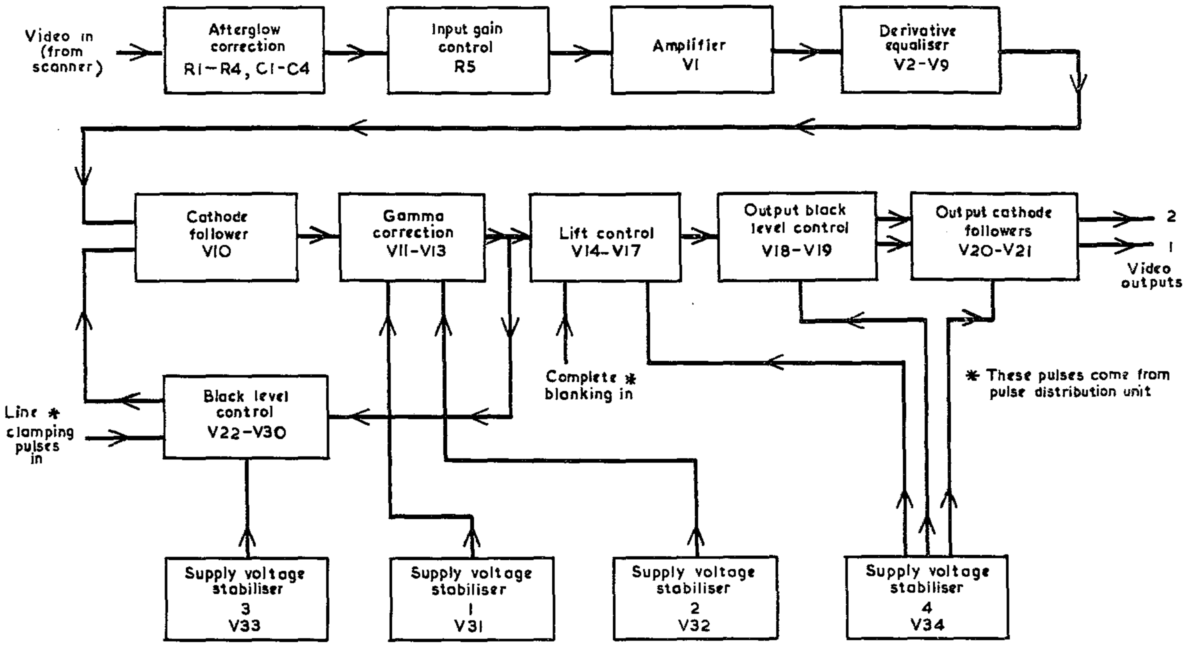

Fig. 5 - Schematic diagram of video control unit

3.2. The Aperture Corrector

Fig. 6 shows a schematic diagram of the corrector. After suitable amplification (in V1) the signal is applied to an aperture corrector (V2 to V9). This corrector utilises the principles of "derivative" equalisation and is very similar in design to a unit developed for the aperture correction of television cameras[10]. Care has been exercised to ensure the generation of true derivative signals throughout the required frequency band of 0 to 3 Mc/s and a phase-corrected low-pass filter is included in order to limit the output spectrum of the corrector to this band.

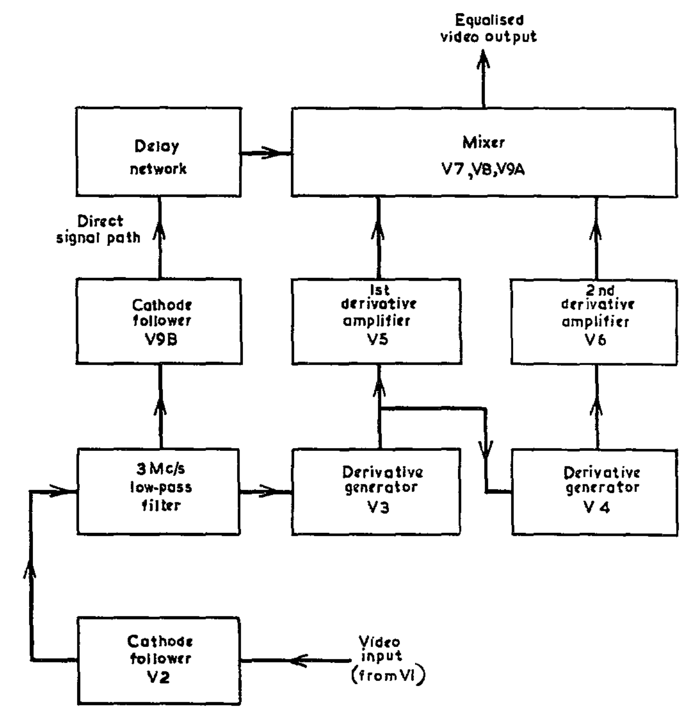

Fig. 6 - Derivative equaliser schematic diagram

The signal passes from the input amplifier V1, through the cathode follower V2, the 3 Mc/s low-pass filter, and then is split into two paths. One path (the direct-signal path) includes a delay network to compensate for signal delay in the derivative generators and is connected to one of the inputs of a mixer formed by V7, V8 and V9A; the other path

leads to the first derivative generator V3. Part of the first derivative generator output passes to the second derivative generator V4 and the outputs of V3 and V4 are passed, through separate variable-gain amplifiers V5 and V6, to each of the two remaining inputs of the mixer already mentioned. The derivatives are each produced by an iron-dust-cored transformer in the anode circuit of a triode[10].

As outlined in Section 2, the correction of aperture loss is carried out by the addition, with reverse polarity, of the second derivative only. The corrector described also includes the facility of adding the first derivative of the signal. By careful use of the first derivative minor distortions of group delay within earlier scanner circuits may be substantially eliminated (see Section 2.2.1).

The signal output from the aperture corrector is therefore sensibly free from group-delay distortion and contains no noise components of frequency higher than 3 Mc/s.

3.3. The Gamma Corrector

Reference to Fig. 5 shows that the gamma corrector consists of the stages V11 to V13 preceded by a cathode follower V10. As the signal at the grid of V11 has a maximum positive excursion corresponding to black, the cathode follower prevents grid current in V11 loading either the aperture corrector or the black level control circuit. Fig. 7 shows a simplified circuit diagram of the gamma corrector together with the driving cathode follower.

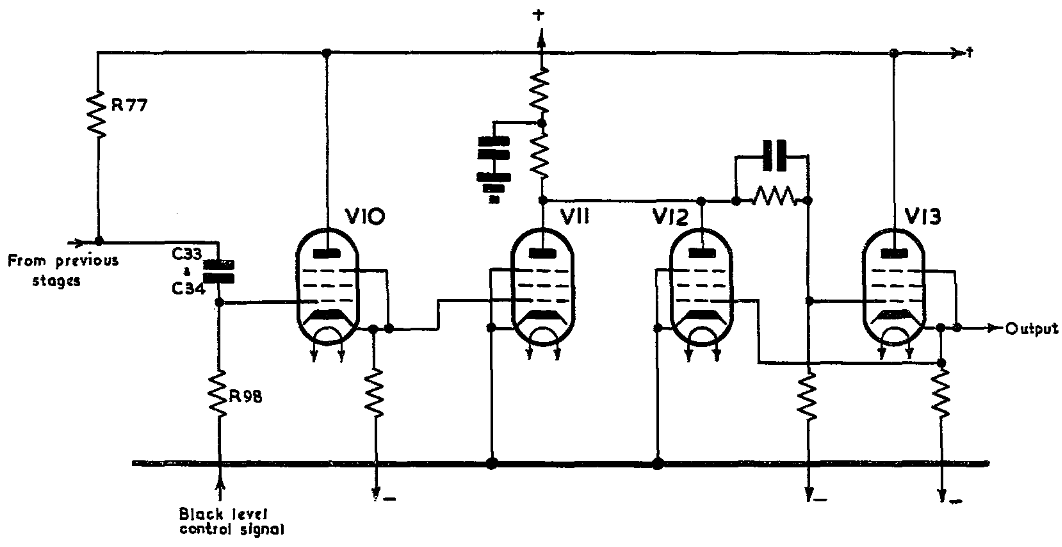

Fig. 7 - Gamma corrector

Negative-going signals from the previous stages are applied to the grid of V10 together with a black level control signal whose derivation will be described later. The black level control signal is such that the total signal at the grid of V10 contains, in correct proportions, all those low frequencies including d.c. which may have suffered attenuation in the signal path from the scanner photocell. From the circuit it will be seen that positive-going signals appearing at the anode of V11 are fed to the output (V13 cathode) and to the grid of the non-linear pentode V12,

whose anode is connected in parallel with that of V11, thus providing negative feedback. As V12 is biased near cut-off at black level and is driven positively by the signal, the circuit will behave as discussed in Section 2.3.

The required characteristic of V12 may be obtained by an EF80 pentode with a suitably stabilised screen potential of 160 V. A minor contribution to the overall transfer characteristic is made by curvature in the characteristic of V11. The performance of the complete corrector is such as to preserve the correct gamma index over an input signal range greater than 100:1. For special purposes the overall transfer characteristic of the circuit may be made linear by rendering V12 inoperative and reducing the gain of V11 by cathode feedback.

3.3.1. Black Level Stabilisation

The black level control voltage required at the grid of V10 is provided by the circuit shown in Fig. 8. The gamma corrected video signal at the output of V13 is applied to the long-tailed amplifying pair formed by V23 and V22. The amplified signal is then fed to one grid of the pair of valves V24 and V25; the other grid is held at a constant potential. The common cathode leads of V24 and V25 are returned to a pulse operated pentode V29, thus V24 and V25 only pass current when V29 conducts. V29 is fed by the positive going clamp pulses amplified by V30. During the clamping interval the amplitudes of the pulses appearing at the anodes of V24 and V25 will depend upon the relative potentials of their two grids.

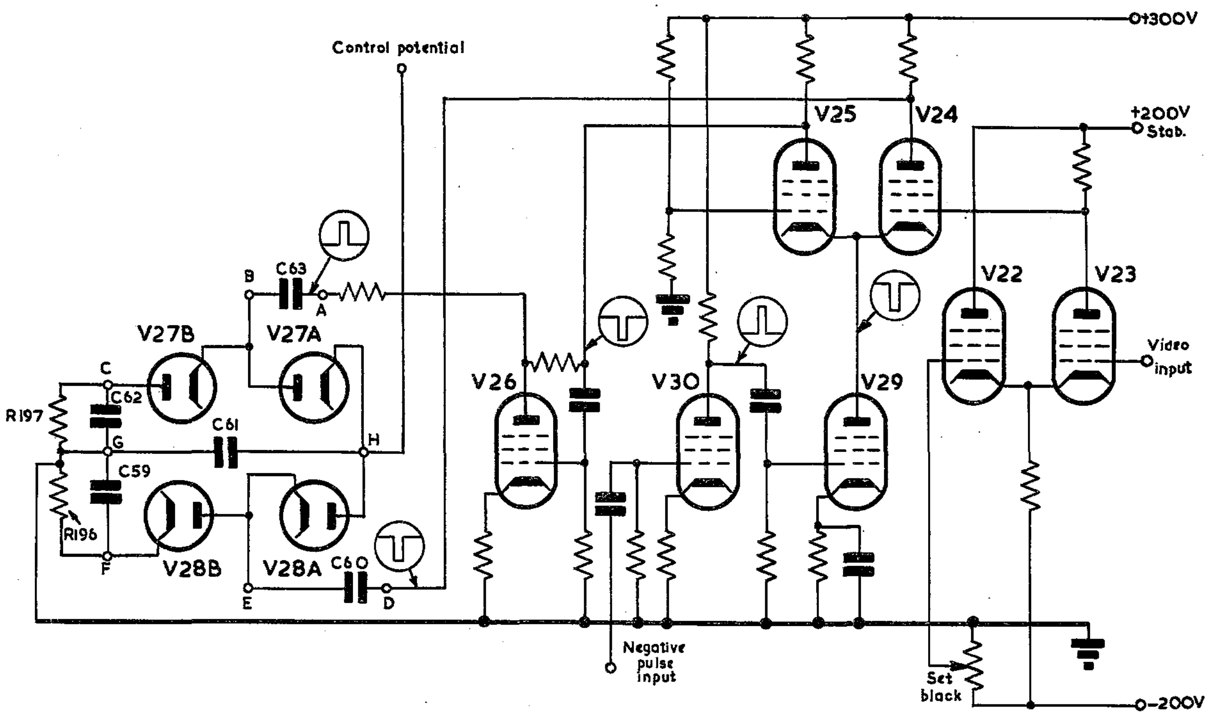

Fig. 8 - Black level control circuit

As the clamping pulse occurs during the interval when the signal level corresponds to black (the line-flyback blanking-period in the scanner), the amplitudes of the two pulses will be determined by the relation between the fixed potential at the grid of V25 and the black level potential applied to the grid of V24.

One of the two pulses is fed to an anode follower stage V26 giving unity gain with polarity reversal. Thus two pulses of opposite polarity are now available such that the sum of their amplitudes is constant and the difference of their amplitudes indicates the deviation of black level potential from a fixed value. The two pulses are now fed to a four-diode circuit producing a control waveform consisting of the integral of the difference between the two input pulses.

If the two pulses are equal in amplitude (the condition obtained for a correct black level potential) the circuit may be bisected along GH and the diodes considered in separate pairs. Under these conditions the positive pulses at A will charge C63, via V27A, until the negative potential at B is equal to the pulse amplitude. V27B will also charge C62 until the potential at C assumes the same value. Similar considerations applied to the negative pulses at D and to the diodes V28A and V28B show that the positive potential at F is equal to the amplitude of the pulse at D, and for equal input pulses the potential of F will exactly equal, but with opposite polarity, that at C.

If an error in black level is indicated by, say, an increase of the pulse at A, and a decrease of that at B, V27A will conduct and the potential at H will rise. An error of opposite sense will cause the potential of H to fall (via V28A). Between pulses, both V27A and V28A are non-conducting and therefore the point H is isolated. The voltage across C61 has a stepped waveform.

Reference to Fig. 7 shows that this correcting voltage undergoes further integration due to R98 together with C33 and C34. The previous load resistor R77 permits some of the first integrator waveform (across C61) to appear at the grid of V10. This constitutes the damping component of the complete black-level stabiliser response.

3.4. The Blanking Gate and Output Circuits

The remainder of the signal path shown in Fig. 5 is concerned with the insertion of blanking pulses and the provision of suitable output signals.

The signal, including the full d.c. component, is passed from the gamma corrector to a direct-coupled feedback amplifier having a low output impedance. From the amplifier the signal is applied to one anode of a pair of diodes: the two cathodes in parallel are connected to a suitable source of blanking pulses. The second anode forms the output terminal of this gate. Given suitable d.c. conditions a signal path exists between the two anodes which is interrupted for the duration of each blanking pulse. Adjustment of pedestal is carried out by the variation of d.c. conditions in the preceding direct-coupled amplifier.

From the gate the signal is amplified in a further direct-coupled amplifier which in turn drives two output cathode followers. Small variations in the d.c. conditions of this amplifier permit the potential of black level in the output signal to be set to zero.

3.5. Auxiliary Circuits

The auxiliary stages of a video control unit consist of voltage stabilisers providing low impedance supplies to various points in direct-coupled circuits. Each

stabiliser consists of a cathode follower whose grid is held at a fixed potential by high stability resistors.

3.6. The Pulse Distribution Unit

Apart from power supplies, the remaining unit which completes the triple channel consists of several pulse distribution amplifiers, each taking drive from the system master waveform generator and supplying suitable pulses to the various circuits of both the triple video channel and the scanner.

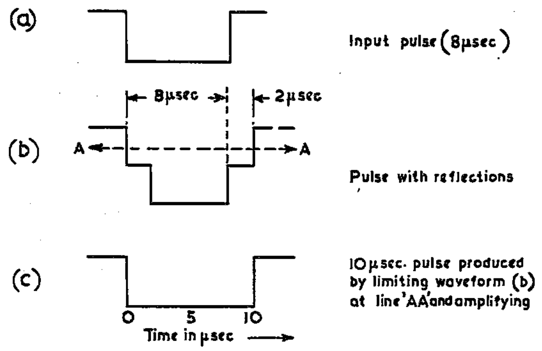

Fig. 9 - Pulse forming by delay line

Only one function carried out by this pulse distribution unit is worthy of further comment. This is concerned with the provision of a $10\,\mu$sec line-trigger/blanking pulse required for both time base synchronisation and line-flyback suppression in the scanner. The normal line drive pulse supplied to the distribution unit has a duration of $8\,\mu$sec. These pulses are fed to the input of a $1\,\mu$sec open-ended delay line: the reflected pulse returns, therefore, with a delay of $2\,\mu$sec and the same polarity. The resultant wave has a stepped form and a duration, between initial and final edges, of $10\,\mu$sec. Limiting permits the formation of a "clean" $10\,\mu$sec pulse. The above procedure is illustrated in Fig. 9.

4. PERFORMANCE

The triple channel described has proved fully satisfactory in performance and has adequate stability for day to day operation. The gamma correction circuits together with carefully designed colour separation in the scanner[1] have permitted the very satisfactory colour reproduction of slides, even when direct comparison is made with the same pictures optically projected.

The equalisation available permits test slides to be fully resolved in terms of the 3 Mc/s bandwidth available and the transient response shows the group-delay distortion to be negligible. The triple channel has been successfully used with an experimental 35 mm slide scanner and with another, developed later, providing both slide and 16 mm motion-picture film facilities[2]. Recent experience with this latter combination has shown that by minor modifications to the black-level control circuit, the triple video channel unit may be operated with input signals having poor signal-to-noise ratios. These modifications are included in the full circuit diagram of a video control unit which is reproduced (Figs. 10a, b and c) for those requiring full design information.

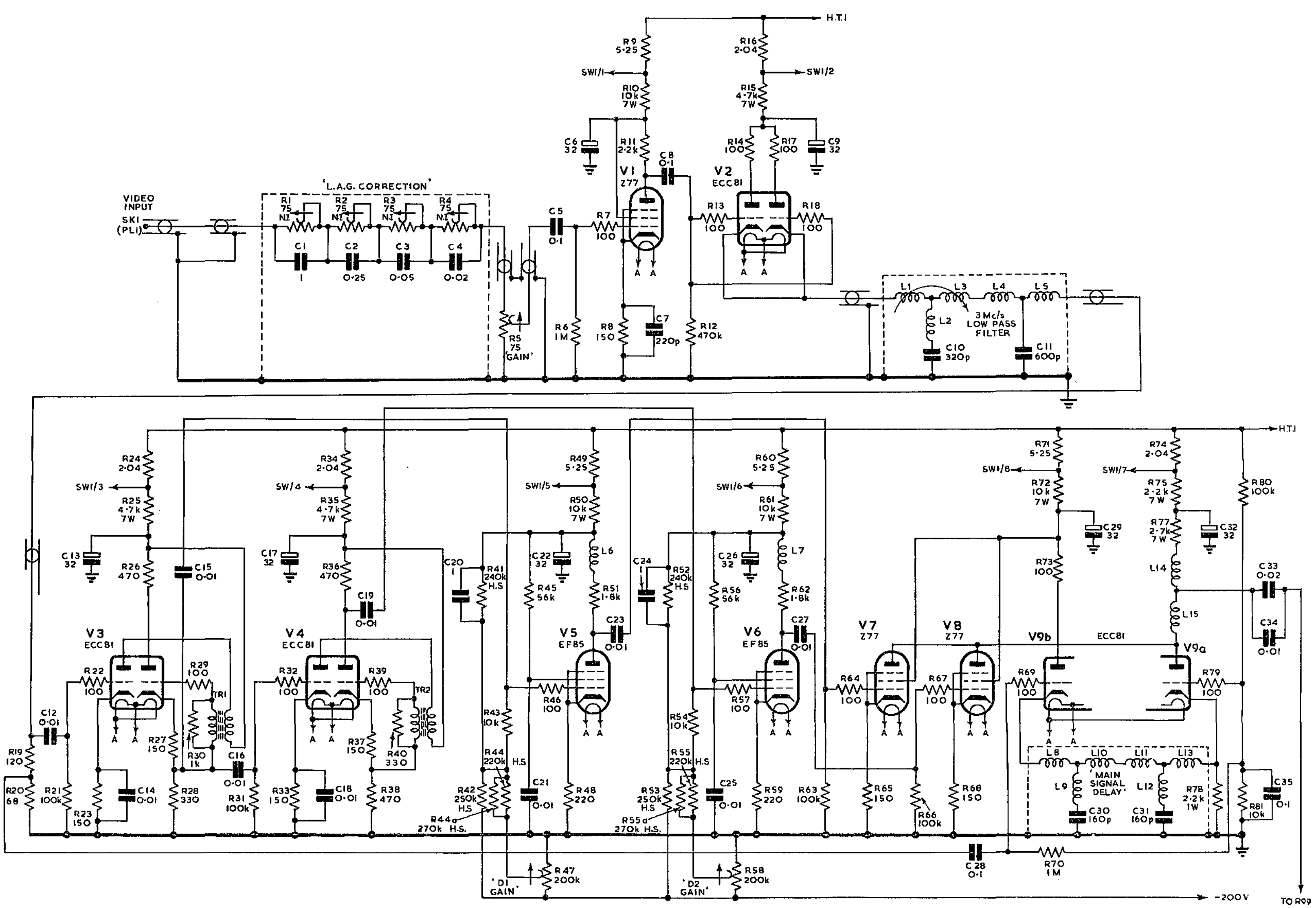

Fig. 10(a) - Video control unit — afterglow and aperture correction

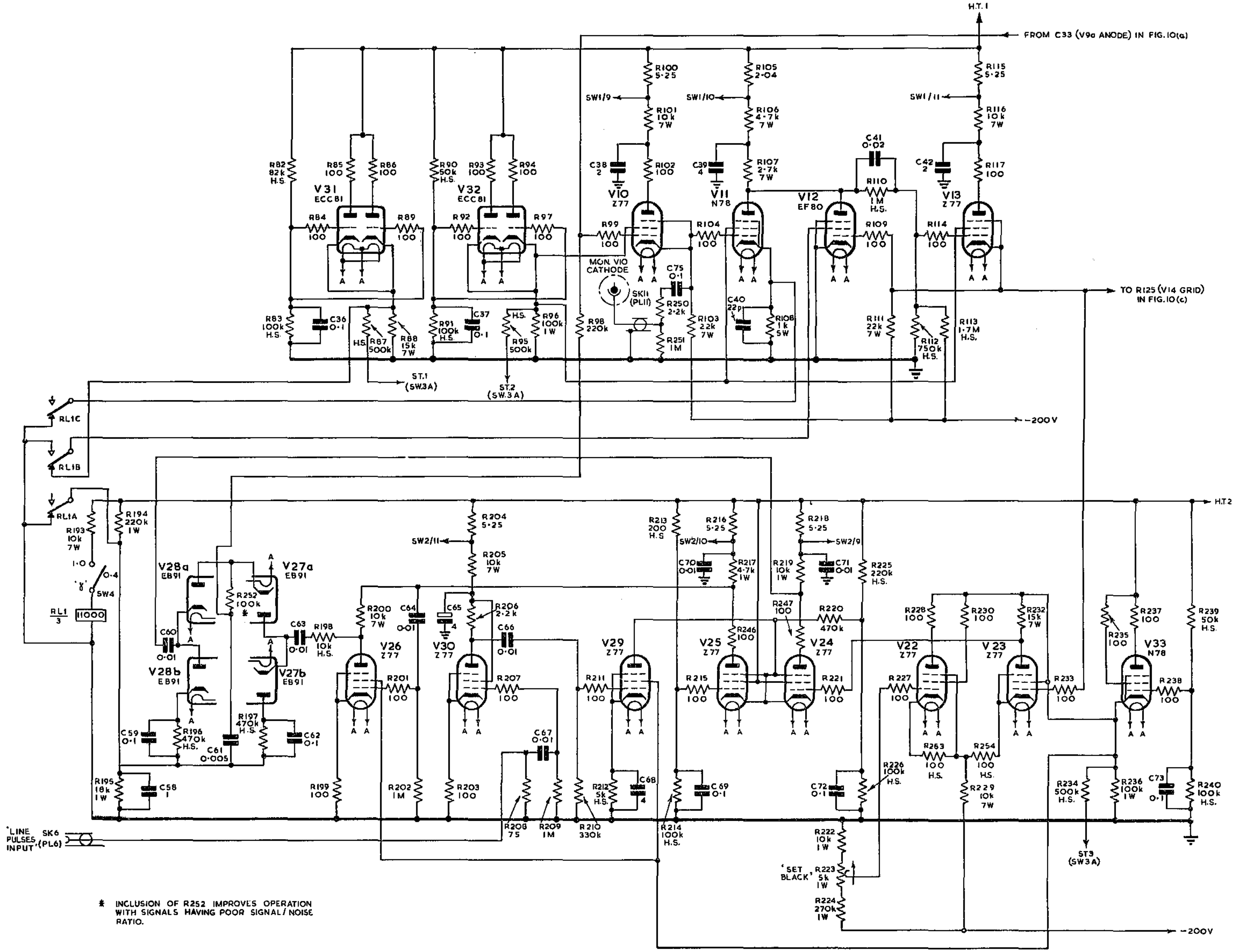

Fig. 10(b) - Video control unit — gamma correction and black level stabilisation

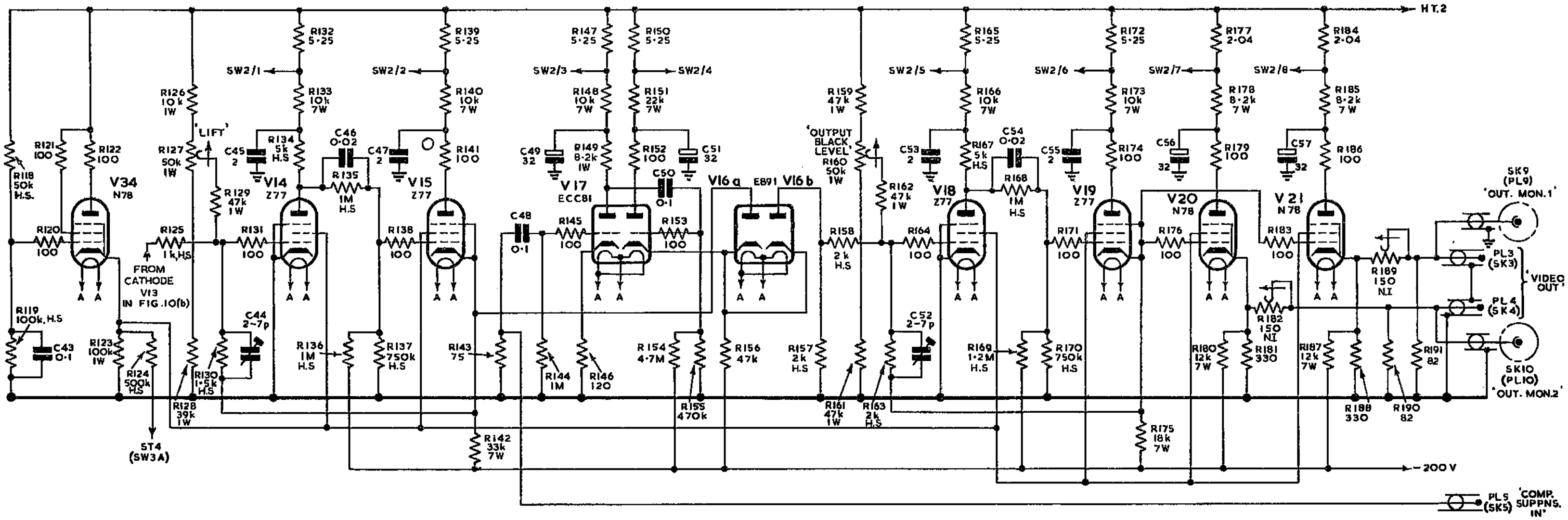

Fig. 10(c) - Video control unit — blanking insertion and output

5. ACKNOWLEDGEMENT

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APPENDIX

The normalised transfer function of the afterglow corrector network shown in Fig. 2 is

$$g_1(p) = \frac{R_o}{R_o + \frac{1}{2}\sum_{r=1}^{n} \frac{R_r}{1 + p\, C_r R_r}} \tag{1}$$

It follows that the transfer function representing the cathode-ray tube response, including afterglow, is the reciprocal of (1)

$$g_2(p) = 1 + \frac{1}{2}\sum_{r=1}^{n} \frac{R_r/R_o}{1 + p\, C_r R_r} \tag{2}$$

$$= 1 + k_1 \frac{\alpha_1}{\alpha_1 + p} + k_2 \frac{\alpha_2}{\alpha_2 + p} + \dots + k_n \frac{\alpha_n}{\alpha_n + p} \tag{3}$$

where $k_n = \dfrac{R_n}{2 R_o}$ etc., and $\alpha_n = \dfrac{1}{C_n R_n}$ etc.

The afterglow characteristic, in terms of unit impulse excitation, may be obtained by taking the inverse Laplace transform of (3).

Thus

$$\mathrm{LT}^{-1} \cdot g_2(p) = F(t) = \delta(t) + \alpha_1 k_1 e^{-\alpha_1 t}$$
$$+ \alpha_2 k_2 e^{-\alpha_2 t} + \dots + \alpha_n k_n e^{-\alpha_n t} \tag{4}$$

in which $\delta(t)$ is unit impulse and the remaining terms on the right hand side describe the afterglow. The latter has been plotted in Fig. 11, using the circuit values of a corrector employing four time-constants determined by the method illustrated in Fig. 1. It is to be noted that the afterglow calculated in this way is identical with that resulting from the sudden removal of a constant excitation in the absence of scanning and conforms with the usual definition of afterglow.

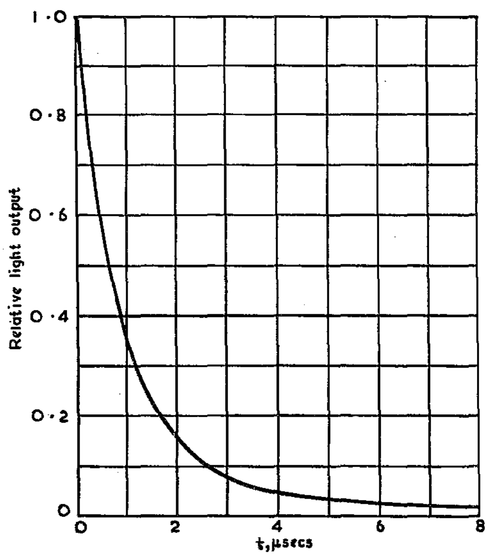

Fig. 11 - Afterglow characteristic of P15 phosphor